Section E : Radioactivity

III Nuclear Energy

(Revision Course)

PHYSICS

CW Sham

& His Team

2015 DSE 超過47%^學生考獲Level 5或以上

(全港比率只有27.1%) 截至2015年8月20日，透過遵理網上成績登記系統及電話調查紀錄。

College

BEACON

遵理學校

Diploma of Secondary Education

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1. Nuclear reaction (核作用)

(i) Conservation Laws (守恆定律)

✧ **In all nuclear reactions, the following two Conservation Laws must be obeyed :**

① **Conservation of Mass** (質量守恆)

Total mass number A (質量數) is balanced at both sides of the nuclear equation.

② **Conservation of Charge** (電荷守恆)

Total atomic number Z (原子序數) is balanced at both sides of the nuclear equation.

✧ **Mass number is not the actual mass. It is an integer representing the approximate mass.**

(ii) Types of nuclear reactions (各種不同的核反應)

✧ **Radioactive transformation** (放射轉變)

* An unstable nucleus undergoes spontaneous decay to emit α, β or γ radiations.

① nucleus with too many protons gives α decay : $^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$

② nucleus with too many neutrons gives β decay : $^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + {}^{0}_{-1}e$

③ nucleus with too much energy gives γ decay : $^{A}_{Z}X \longrightarrow {}^{A}_{Z}X + \gamma$

✧ **Bombardment of particle** (粒子撞擊)

* A nucleus is bombarded by a particle and undergoes transformation.

* Examples : $^{14}_{7}N + {}^{1}_{0}n \longrightarrow {}^{14}_{6}C + {}^{1}_{1}p$

$^{27}_{13}Al + {}^{4}_{2}He \longrightarrow {}^{30}_{15}P + {}^{1}_{0}n$

✧ **Nuclear fission** (核裂變)

* An unstable nucleus splits up into smaller pieces of fragment nuclei by the trigger of neutron.

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2\,{}^{1}_{0}n$$

✧ **Nuclear fusion** (核聚變)

* Two small nuclei combine to form a large nucleus at extremely high temperature.

$$^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{3}_{2}He + {}^{1}_{0}n$$

Example : Which of the following equations represents(s) possible nuclear reaction(s) ?
(1991)

睇 balance.

(1) $^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \longrightarrow ^{30}_{15}\text{P} + {}_{1}\text{proton}$

(2) $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \longrightarrow ^{4}_{2}\text{He} + \text{neutron}$

(3) $^{234}_{90}\text{Th} \longrightarrow ^{234}_{91}\text{Pa} + \beta \text{ particle}$

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

Example : Which of the following equations represent(s) possible nuclear reactions ?
(1986)

(1) $^{10}_{5}\text{B} + \text{neutron} \longrightarrow ^{6}_{3}\text{Li} + ^{4}_{2}\alpha \text{ particle}$

(2) $^{210}_{83}\text{Bi} \longrightarrow ^{210}_{84}\text{Po} + \beta \text{ particle}$

(3) $^{14}_{7}\text{N} + \alpha \text{ particle} \longrightarrow ^{17}_{8}\text{O} + \text{proton}$

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

Example : Which of the following nuclear reactions is a fission ?
(2008)

A. $^{235}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{144}_{56}\text{BA} + ^{89}_{36}\text{Kr} + 3\,^{1}_{0}\text{n}$

B. $^{238}_{92}\text{U} + ^{1}_{0}\text{n} \rightarrow ^{239}_{94}\text{Pu} + 2\,^{0}_{-1}\text{e}$

C. $^{238}_{92}\text{U} + ^{14}_{7}\text{N} \rightarrow ^{248}_{99}\text{Es} + 4\,^{1}_{0}\text{n}$

D. $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{1}_{0}\text{n}$

Example : Which of these is a nuclear fusion reaction ?
{SP}

A. $^{235}_{92}\text{U} + \text{n} \longrightarrow ^{144}_{56}\text{Ba} + ^{90}_{36}\text{Kr} + 2\text{ n}$

B. $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \longrightarrow ^{4}_{2}\text{He} + \text{n}$

C. $^{14}_{7}\text{N} + \text{n} \longrightarrow ^{14}_{6}\text{C} + ^{1}_{1}\text{H}$

D. $^{238}_{92}\text{U} \longrightarrow ^{234}_{90}\text{Th} + \alpha$

2. The Mass-Energy Relationship (質能關係式)

(i) Einstein's mass-energy relationship (愛因斯坦質能關係式)

✧ **Einstein proposed that energy E and mass m are equivalent and inter-related by**

{E4} $\boxed{\Delta E = \Delta m\, c^2}$ $E=mc^2$

where c is the speed of light in vacuum and is equal to 3×10^8 m s^{-1}. { $c = 3 \times 10^8$ m s^{-1} }

✧ **According to Einstein's equation, mass Δm can be converted to energy ΔE and vice versa, energy ΔE can also be converted to mass Δm.**

✧ **Suppose 1 kg of mass can be converted to energy, the amount of energy released is**

$$\Delta E = (1) \times (3 \times 10^8)^2 = 9 \times 10^{16} \text{ J}$$

✧ **Huge amount of energy ΔE can be obtained by converting small amount of mass.**

(ii) The atomic mass unit (原子質量單位)

✧ **The atomic mass unit u is equal to $\frac{1}{12}$ of the mass of one carbon-12 atom.**

✧ **The mass of a carbon-12 atom is exactly** 12 u **and the molar mass of carbon-12 is** 12 g.

$$\therefore \ 1 \text{ u} = \frac{1\times10^{-3}}{6.02\times10^{23}} = 1.661 \times 10^{-27} \text{ kg}$$ { u $= 1.661 \times 10^{-27}$ kg }

(iii) Energy equivalent of mass (能相等於質)

✧ **The energy equivalent of the mass of 1 u can be found by**

$$E = m c^2 = (1 \times 1.661 \times 10^{-27})(3 \times 10^8)^2 = 1.49 \times 10^{-10} \text{ J}$$

$$\therefore \ E = \frac{1.49\times10^{-10}}{1.6\times10^{-19}} = 9.31 \times 10^8 \text{ eV} = 931 \text{ MeV}$$

✧ **The energy equivalent of** 1 u **is equal to** 931 MeV. { 1 u = 931 MeV }

✧ **Interchange between mass m and energy E :**

① $(E\,/\,\text{J}) = (m\,/\,\text{kg}) \times (3 \times 10^8)^2$ $E=mc^2$

② $(E\,/\,\text{MeV}) = (m\,/\,\text{u}) \times 931$ 1 u = 931 MeV

✧ **Note that two methods would give slightly different answers, but both are accepted.**

(iv) Mass defect (質量虧損)

$$A \xrightarrow[\Delta m = m_A - m_B]{m_A > m_B} B + \boxed{\text{energy}} \equiv \text{mass}$$

✧ **In a nuclear reaction, if energy is released, then the total mass of the product is less than the total mass of the reactants.**

✧ **The difference of mass is called the mass defect. The energy equivalent of the mass defect is the energy released.**

✧ **In the following nuclear reactions, energy is released, thus the total mass of the products must be less than the total mass of the reactants.**

① α decay
② β decay
③ γ emission
④ nuclear fission
⑤ nuclear fusion

mass defect

Example : Which nuclear reactions are accompanied with a mass defect ?

✓ (1) the union of hydrogen isotopes to form helium

$${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \rightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n}$$ fusion

✓ (2) the natural radioactive decay of radium-226

$${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$$ α decay

✓ (3) the emission of a β-particle from a nucleus

$${}^{1}_{0}\text{n} \rightarrow {}^{1}_{1}\text{H} + {}^{0}_{-1}\text{e}$$

Example : {2014} A radium nucleus decays to a radon nucleus by emitting an α-particle. The energy released in the process is 4.9 MeV. Compared to the mass of a radium nucleus, the total mass of a radon nucleus and an α-particle is

A. 5.4×10^{-11} kg less.
B. 5.4×10^{-11} kg more.
C. 8.7×10^{-30} kg less.
D. 8.7×10^{-30} kg more.

Ra → Rn + α

Method ① : $\Delta E = \Delta m\, c^2$

$\therefore \underbrace{(4.9 \times 10^6 \times 1.6 \times 10^{-19})}_{\text{J}} = \Delta m \times (3 \times 10^8)^2 \qquad \therefore \Delta m = 8.7 \times 10^{-30}$ kg

Method ② : $\Delta m = 4.9 \times \dfrac{1}{931} = 5.263 \times 10^{-3}\ \text{u} = 5.263 \times 10^{-3} \times 1.661 \times 10^{-27}\ \text{kg} = 8.7 \times 10^{-30}$ kg

Example : Radium226 ($^{226}_{88}\text{Ra}$) undergoes α-decay into radon (Rn).

{2012} (a) Write a nuclear equation for the decay. (2 marks)

$$^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\alpha$$

(b) Given : mass of a radium nucleus = 226.0254 u
mass of a radon nucleus = 222.0176 u
mass of an α-particle = 4.0026 u

Calculate the energy released in the decay in MeV. (2 marks)

Mass defect = 226.0254 − 222.0176 − 4.0026 = 0.0052u

Energy released = 0.0052 × 931 = 4.84 MeV

Example : Iodine-131 ($^{131}_{53}\text{I}$) is a common radioactive nuclide found in radioactive waste from nuclear power plants. It undergoes

[2012] β decay to a stable nuclide Xenon-131 with a half-life of 8.02 days.

(a) Estimate the initial activity of 1 kg of Iodine-131, given that mass of one mole of Iodine-131 is 131 g. (3 marks)

molar

$$N_0 = \frac{1}{131\times10^{-3}} \times 6.02\times10^{23} = 4.60\times10^{24}$$ [1]

M → N → A

$$k = \frac{\ln 2}{t_{1/2}} = \frac{\ln 2}{8.02\times24\times3600} = 1.00\times10^{-6}\ \text{s}^{-1}$$ [1]

$$A_0 = k N_0 = (1.00\times10^{-6})(4.60\times10^{24}) = 4.60\times10^{18}\ \text{Bq}$$ [1]

(b) Assuming that the mass loss of the decay of Iodine-131 becomes heat, estimate the initial heating power of 1 kg of Iodine-131 in the unit W. (4 marks)

Given : mass of an Iodine-131 nucleus = 130.90612 u
mass of a Xenon-131 nucleus = 130.90508 u
mass of an electron = 0.00054 u

$$\Delta m = 130.90612 - 130.90508 - 0.00054 = 5\times10^{-4}\ \text{u}$$ [1]

1 $$E = (5\times10^{-4}) \times \underbrace{(931\times10^{6}\times1.6\times10^{-19})}_{931\ \text{MeV}} \rightarrow \text{J}$$ [1]

$$= 7.45\times10^{-14}\ \text{J}$$ [1]

OR

2 $$E = \Delta m\, c^2 = (5\times10^{-4}\times1.661\times10^{-27})\times(3\times10^{8})^2$$ [1]

$$= 7.47\times10^{-14}\ \text{J}$$ [1]

$$\boxed{P = E A_0} = (7.45\times10^{-14})(4.60\times10^{18}) = 3.43\times10^{5}\ \text{W}$$ [1]

(c) Even after a reactor is shut down and nuclear fission completely stopped, fission products like Iodine-131 keep on producing heat. Explain why we cannot stop the Iodine-131 from producing heat. (2 marks)

The decay of a radioisotope is determined by the half-life (OR decay constant). [1]

It cannot be changed by human factors or surrounding factors. [1]

3. Nuclear fission (核裂變)

(i) Fission of Uranium (鈾之裂變)

✧ **The heavy metal Uranium is a mixture of two isotopes : $^{235}_{92}U$ (0.7%) and $^{238}_{92}U$ (99.3%).** α decay.

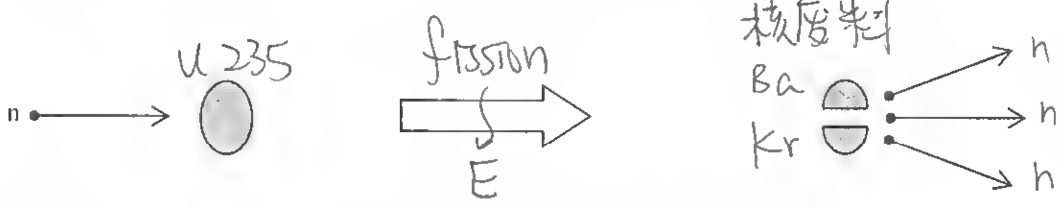
✧ **Only the isotope U-235 can undergo fission.**

✧ **When a Uranium-235 nucleus is hit by a neutron, it undergoes fission and splits into two smaller fragment nuclei** (daughter nuclei), **together with a small number of fission neutrons.**

✧ **Possible examples of fission :**

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{144}_{56}Ba + {}^{90}_{36}Kr + 2\,{}^{1}_{0}n$$

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n$$



(ii) Energy release in nuclear fission (核裂變釋放之能量)

✧ **Consider the following fission process :**

$$^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n$$

Mass of the U-235 = 235.0439 u

Mass of the Ba-141 = 140.9139 u

Mass of the Kr-92 = 91.8973 u

Mass of a neutron = 1.0087 u

Mass defect = (235.0439 + 1.0087) − (140.9139 + 91.8973 + 1.0087 × 3) = 0.2153 u

$\because$ 1 u = 931 MeV

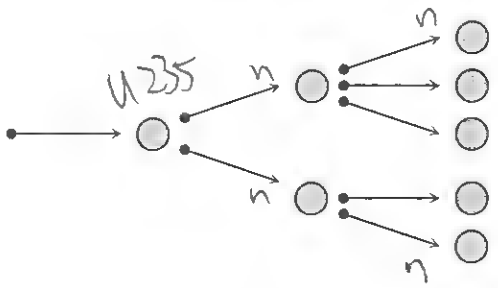
$\therefore$ Energy equivalent of the mass defect = 0.2153 × 931 = 200 MeV

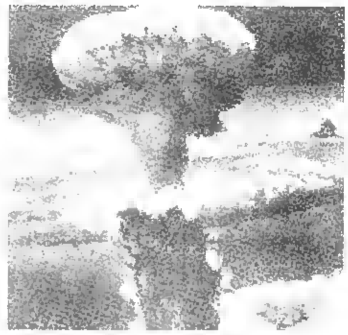
$\therefore$ Energy release for each fission = 200 MeV

✧ **The energy released during fission is million of times greater than that released in chemical reactions.**

✧ **The fission energy appears mostly in form of kinetic energy of the fission products which fly apart at great speed.** (KE ∝ T)

(iii) Chain reaction (鏈式反應)





- ✧ **Chain reaction is made possible by the fission neutrons which trigger the further fissions of the remaining U-235 nuclei.**

- ✧ **As natural uranium contains mostly U-238 but only a small percentage of U-235** (0.3%), **the uranium fuel in an atomic bomb** (原子彈) (nuclear bomb 核彈) **is enriched to about 80% so that chain reaction can occur continuously.**

- ✧ **Large amount of energy can thus be released by an atomic bomb in a very short time to give an explosion.**

Example : Which of the following conditions is/are necessary to sustain the chain reaction in the nuclear fission of uranium-235 ?

(2009) ✗ (1) Each fission produces a large amount of energy.

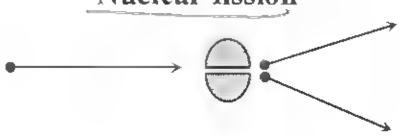
✓ (2) At least one neutron is released in each fission.

(3) Each fission produces two smaller nuclei.

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

(iv) Difference between nuclear fission and radioactive decay (核裂變和放射衰變的不同)

Nuclear fission



Radioactive decay

Nuclear fission	Radioactive decay
① The nucleus is divided into two large fragments.	① The nucleus remains as a whole body.
② Neutrons are emitted.	② α, β and γ are emitted.
③ The process can be initiated whenever it is desirable.	③ The process involves a characteristic half-life.

Example : One of the possible fission reaction is described by the following equation :

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{143}_{56}Ba + ^{90}_{36}Kr + 3^{1}_{0}n + 193.18 \text{ MeV} \quad E = \Delta M$$

Mass of $^{235}_{92}U$ = 235.0439 u ; mass of $^{143}_{56}Ba$ = 142.9067 u ; mass of $^{90}_{36}Kr$ = 89.9123 u ;

(a) Calculate the mass, in atomic mass unit, of a neutron. Express the answer in 4 decimal places.

$$\Delta m = \frac{193.18}{931} u = 0.2075 u$$

$$\therefore (235.0439 \text{ u}) = (142.9067 \text{ u}) + (89.9123 \text{ u}) + 2\,m_n + (0.2075 \text{ u})$$

$$\therefore m_n = 1.0087 \text{ u}$$

M u = 235g

(b) If a fuel rod consumes 1.2 mg of U-235 isotope per second, what is the power released by the fuel rod ?

$$\frac{N}{t} = \frac{1.2\times10^{-3}}{235} \times 6.02\times10^{23} = 3.074\times10^{18} \quad M \rightarrow N$$

$$P = EA \quad P = \frac{N}{t}E = (3.074\times10^{18}) \times \underbrace{(193.18\times10^{6}\times1.6\times10^{-19})}_{2} = 9.50\times10^{7} \text{ W}$$

Example : {SP} In April 1986, a disastrous nuclear accident happened at the Chernobyl Nuclear Power Station. A large quantity of various radioactive substances was released and spread to neighbouring countries. The radiation levels recorded in these countries were much higher than the normal background radiation count rate.

(a) One of the radioactive isotopes released in the accident was caesium-137 (Cs-137). The following equation shows how Cs-137 is produced :

$$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{137}_{55}Cs + ^{95}_{37}Rb + x\,^{1}_{0}n$$

Given : $^{235}_{92}U$ = 235.0439 u ; $^{137}_{55}Cs$ = 136.9071u ; $^{95}_{37}Rb$ = 94.9399 u ; $^{1}_{0}n$ = 1.0087 u.

(i) What is the value of x ? (1 mark)

$$x = 235 + 1 - 137 - 95 = 4$$

(ii) Find the energy release in the fission of one U-235 nuclide in MeV. (2 marks)

$$\Delta m = 235.0439 - (136.9071 + 94.9399 + 3\times1.0087) = 0.1708 \text{ u}$$

$$E = 0.1708 \times 931 = 159 \text{ MeV}$$

(iii) The half-life of Cs-137 is 30 years. A soil sample contaminated by Cs-137 has an activity of 1.2×10^{6} Bq (disintegration per second). A physicist comments that the contaminated sample will affect the environment for more than 350 years. Justify the physicist's claim with calculations. It is known that the activity of an uncontaminated soil sample is 200 Bq. (2 marks)

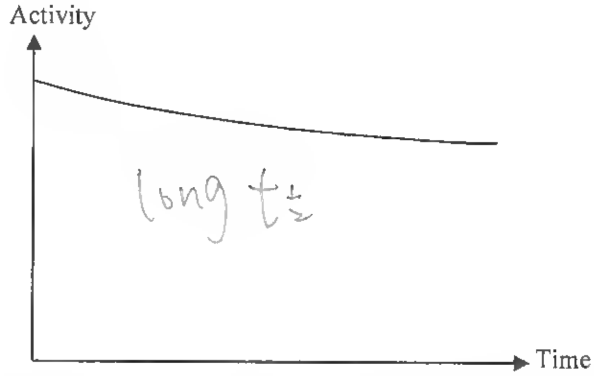
$$A = (1.2\times10^{6})\times e^{-(\frac{\ln 2}{30})\times(350)} = 369 \text{ Bq} \quad \textbf{OR} \quad A = (1.2\times10^{6})\times(\tfrac{1}{2})^{350/30} = 369 \text{ Bq} \quad [1]$$

This activity is larger than 200 Bq. $A = A_0 e^{-kt}$ or $A = A_0\left(\frac{1}{2}\right)^{t/t_{\frac{1}{2}}}$

The sample will contaminate the environment for more than 350 years. [1]

(v) Disposal of radioactive waste (輻射性廢料的棄置)

- ✧ In the nuclear reactors, various radioactive wastes are produced.
- ✧ In order to reduce the harmful effect on the environment, the disposal of radioactive waste is a serious problem.



- ✧ **Some radioactive wastes have very short half-lives** (e.g. 5 s ; 5 min.). **Their activity quickly drops to a harmless level after keeping for some time.**
- ✧ **Some radioactive wastes have long half-lives** (e.g. 5 years). **Their activities are constant and stable over a long period of time. They are kept in sealed steel containers** (密封鋼製容器) **and stored underground.**
- ✧ **Some radioactive wastes have extremely long half-lives** (e.g. 50 000 years). **They can be hit by neutrons and converted to another radioactive nuclide with shorter half-lives.**

Example : In nuclear power stations, radioactive waste material is produced in the power generation process. Disposal of this waste may be a problem. One solution is to bury the waste underground. The isotope technetium-99 ($^{99}_{43}$Tc) is a major waste produced, and it has a long half-life of 2.1×10^5 years. The isotope is first converted into another isotope technetium-100, by combining it with a neutron, before it is disposed of. Technetium-100 has a half-life of 15 s.

(a) Write down the equation for the above reaction.

Equation : $^{99}_{43}\text{Tc} + {}^{1}_{0}\text{n} \longrightarrow {}^{100}_{43}\text{Tc}$

(b) Explain why this conversion is necessary.

After the conversion, Tc-100 has a very short **half-life, and thus its activity quickly** drops **to a** harmless **level.**

(c) Find the time required for the activity of a sample of technetium-100 to drop to 0.1% of its initial value.

By $A = A_0\left(\frac{1}{2}\right)^{t/t_{1/2}}$

$\therefore\ 0.1\% = \frac{1}{2}^{t/15}$

$\therefore\ t =$ 149 s

4. Nuclear fusion (核聚變)

(i) Fusion of hydrogen (氫的聚變)

✧ **Two small nuclei such as hydrogen combine to form a large nucleus such as helium.**

✧ **Possible fusion comes from different hydrogen isotopes (氫之同位素) :**

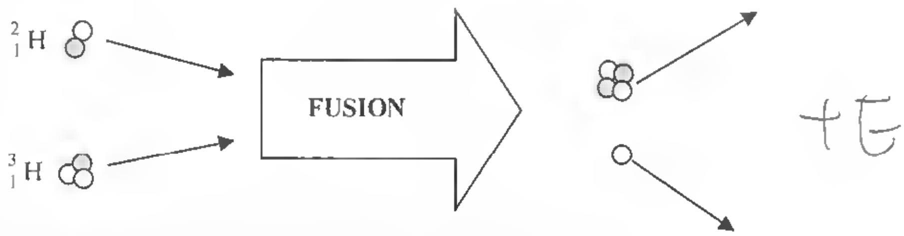
① hydrogen-1 (氕) ^1_1H (p)

② hydrogen-2 (deuterium 氘) ^2_1H

③ hydrogen-3 (tritium 氚) ^3_1H

$$^2_1H + ^2_1H \longrightarrow ^3_2He + ^1_0n$$

$$^2_1H + ^3_1H \longrightarrow ^4_2He + ^1_0n$$



✧ **Large amount of energy is released during nuclear fusion.**

(ii) Energy release in nuclear fusion (核聚變釋放之能量)

✧ **One of the fusion reaction :** $^2_1H + ^2_1H \longrightarrow ^3_2He + ^1_0n$

Mass of the ^2_1H = 2.0141 u

Mass of the ^3_2He = 3.0160 u

Mass of a neutron= 1.0087 u

$\therefore$ Mass defect = $(2.0141 + 2.0141) - (3.0160 + 1.0087)$ = 0.0035u

$\therefore$ Energy equivalent = 0.0035×931 = 3.26 MeV

$\therefore$ Energy release per fusion = 3.26 MeV

Example : The sun releases huge amount of energy through thermonuclear fusion while at the same time its mass decreases. The {2013} average power released by the sun is about 3.8×10^{26} W. Estimate the decrease in mass of the sun in one second.

A. 4.2×10^6 kg
B. 4.2×10^9 kg
C. 1.3×10^{15} kg
D. 1.3×10^{18} kg

$E = Pt = 3.8 \times 10^{26}$ J

$E = mc^2 = 3.8 \times 10^{26} = m(3 \times 10^8)^2$

(iii) Condition for nuclear fusion to occur (進行的核聚變的條件)

✧ **Nuclear fusion is not a spontaneous process. It requires extremely high temperature to achieve the nuclear reaction.** 自发

✧ **Reasons for the extremely high temperature :**

* Fusion can only occur when two positively charged hydrogen nuclei comes very closely.
* To overcome the electrostatic repulsion between them, the two nuclei must have very high speed. 同性相斥
* At high temperature, the hydrogen nuclei have high kinetic energy to achieve high speed.

✧ **Nuclear fusion in stars :**

* All stars (including the Sun) contain hydrogen.
* The temperature in the core of stars is extremely high.
* Fusion occurs continuously in the stars to release solar energy.

✧ **Hydrogen bomb (氫彈) :**

* Hydrogen bomb makes use of nuclear fusion to release large amount of energy.
* To achieve the extremely high temperature, it requires the explosion of an atomic bomb for triggering the fusion reactions.

(iv) Future use of nuclear fusion to generate electricity (未來使用核聚變發電)

✧ **Advantages of using nuclear fusion :**

① There is enormous supply of fuel (hydrogen) in form of water in oceans.

② The waste products of nuclear fusion are not radioactive, thus no waste disposal problem.

✧ **Difficulties of using nuclear fusion to generate electricity :**

① It is not easy to achieve the extremely high temperature safely for nuclear fusion of hydrogen to take place.

② No physical container can withstand such an extremely high temperature.

Example : In the nuclear reactor, deuterium and tritium exist as plasma, which is a mixture of ions at a very high temperature. To start the fusion reaction, the average kinetic energy of the ions in the plasma has to reach the minimum value of 0.2 MeV.

(a) Explain why a very high temperature is needed for nuclear fusion to occur. (2 marks)

To overcome the electrostatic repulsion between the two (positive) nuclei,

the temperature must be very high

so that the ions has sufficient kinetic energy to come close to each other.

(b) Estimate the order of magnitude of the minimum temperature at which fusion of deuterium and tritium nuclei would be possible if the plasma can be regarded as an ideal gas. (2 marks)

$$E_k = \frac{3}{2}\cdot\frac{R}{N_A}\cdot T$$

$$\therefore\ (0.2\times10^6\times1.6\times10^{-19}) = \frac{3}{2}\cdot\frac{(8.31)}{(6.02\times10^{23})}\cdot T$$

$$\therefore\ T = 1.55\times10^9\ \text{K}$$

Order of magnitude of temperature = 10^9 K

Example : Which of the following processes take(s) in the Sun to release solar radiation ?

✓ (1) Nuclear fusion

✗ (2) Nuclear fission

✗ (3) Radioactive decay

Example : The following nuclear reaction represents the two deuterons, ${}^2_1\text{H}$, which combine to form a helium isotope, ${}^3_2\text{He}$, with the release of energy.

$$2\,{}^2_1\text{H} \longrightarrow {}^3_2\text{He} + {}^1_0\text{n} + \text{energy}$$

Which of the following statements are correct ?

✓ (1) This is an example of nuclear fusion.

✗ (2) The reaction is spontaneous.

✗ (3) The total mass of ${}^3_2\text{He}$ and ${}^1_0\text{n}$ is ~~greater~~ < than that of the two ${}^2_1\text{H}$.

✗ (4) The reaction has to be triggered by use of neutrons.

✓ (5) The reaction can only occur at very high temperature.

5. Development of nuclear power (發展核能發電)

(i) Fossil fuel (化石燃料)

✧ **Fossil fuels include : coal (煤); crude oil (石油) and natural gas (天然氣).**

✧ **Disadvantage of fossil fuels :**

① Fossil fuels have limited resources (有限資源).

② Fossil fuels cause air pollution (空氣污染).

③ Fossil fuels produce carbon dioxide that causes the temperature of the earth to increase due to the global greenhouse effect (全球溫室效應).

(ii) Social debate concerning nuclear power (核能發電的社會爭辯)

✧ **Advantages of nuclear power** (核能發電的優點) ← pros

① It is cheaper since the running cost is lower.

② It is clean since it does not produce air pollution, thus cause less harm to our environment.

③ It does not cause global greenhouse effect that makes the temperature of the Earth rise.

④ It reduces the dependence on fossil fuel that has limited supply.

✧ **Disadvantages of nuclear power** (核能發電的缺點) ← cons

① Once accident occurs, it would be very serious.

② The disposal of radioactive wastes causes a serious problem.

③ People resident near the power plant would worry about the leakage of radiation.

④ The capital investment of the nuclear power plant is very high.

Example : (2003) The development of nuclear energy is a controversial issue. Do you support the development of nuclear energy ? State the reasoning to support your point of view. (4 marks)

I support the development of nuclear power since

it is cheaper as the running cost is lower, and [2]

it is clean since it does not produce air pollution and acid rain. [2]

OR

I do not support the development of nuclear power since

it is dangerous as once accident occurs, it would be very serious, and [2]

it is expensive as the capital investment is very high. [2]

< accept other reasonable answers >

List of data, formulae and relationships

Data

molar gas constant	$R = 8.31 \text{ J mol}^{-1} \text{ K}^{-1}$
Avogadro constant	$N_A = 6.02 \times 10^{23} \text{ mol}^{-1}$
acceleration due to gravity	$g = 9.81 \text{ m s}^{-2}$ (close to the Earth)
universal gravitational constant	$G = 6.67 \times 10^{-11} \text{ N m}^2 \text{ kg}^{-2}$
speed of light in vacuum	$c = 3.00 \times 10^8 \text{ m s}^{-1}$
charge of electron	$e = 1.60 \times 10^{-19} \text{ C}$
electron rest mass	$m_e = 9.11 \times 10^{-31} \text{ kg}$
permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-12} \text{ C}^2 \text{ N}^{-1} \text{ m}^{-2}$
permeability of free space	$\mu_0 = 4\pi \times 10^{-7} \text{ H m}^{-1}$
atomic mass unit	$u = 1.661 \times 10^{-27} \text{ kg}$ (1 u is equivalent to 931 MeV)
astronomical unit	$\text{AU} = 1.50 \times 10^{11} \text{ m}$
light year	$\text{ly} = 9.46 \times 10^{15} \text{ m}$
parsec	$\text{pc} = 3.09 \times 10^{16} \text{ m} = 3.26 \text{ ly} = 206265 \text{ AU}$
Stefan constant	$\sigma = 5.67 \times 10^{-8} \text{ W m}^{-2} \text{ K}^{-4}$
Planck constant	$h = 6.63 \times 10^{-34} \text{ J s}$

Rectilinear motion

For uniformly accelerated motion :

$$v = u + at$$

$$s = ut + \tfrac{1}{2}at^2$$

$$v^2 = u^2 + 2as$$

Mathematics

Equation of a straight line	$y = mx + c$
Arc length	$= r\theta$
Surface area of cylinder	$= 2\pi rh + 2\pi r^2$
Volume of cylinder	$= \pi r^2 h$
Surface area of sphere	$= 4\pi r^2$
Volume of sphere	$= \tfrac{4}{3}\pi r^3$

For small angles, $\sin\theta \approx \tan\theta \approx \theta$ (in radian)

Astronomy and Space Science

$U = -\dfrac{GMm}{r}$	gravitational potential energy
$P = \sigma A T^4$	Stefan's law
$\left\lvert\dfrac{\Delta f}{f_0}\right\rvert \approx \dfrac{v}{c} \approx \left\lvert\dfrac{\Delta\lambda}{\lambda_0}\right\rvert$	Doppler effect

Energy and Use of Energy

$E = \dfrac{\Phi}{A}$	illuminance
$\dfrac{Q}{t} = k\dfrac{A(T_H - T_C)}{d}$	rate of energy transfer by conduction
$U = \dfrac{k}{d}$	thermal transmittance U-value
$P = \dfrac{1}{2}\rho A v^3$	maximum power by wind turbine

Atomic World

$\dfrac{1}{2}m_e v_{max}{}^2 = hf - \phi$	Einstein's photoelectric equation
$E_n = -\dfrac{1}{n^2}\left\{\dfrac{m_e e^4}{8h^2 \varepsilon_0{}^2}\right\} = -\dfrac{13.6}{n^2}\text{eV}$	energy level equation for hydrogen atom
$\lambda = \dfrac{h}{p} = \dfrac{h}{mv}$	de Broglie formula
$\theta \approx \dfrac{1.22\lambda}{d}$	Rayleigh criterion (resolving power)

Medical Physics

$\theta \approx \dfrac{1.22\lambda}{d}$	Rayleigh criterion (resolving power)
$\text{power} = \dfrac{1}{f}$	power of a lens
$L = 10\log\dfrac{I}{I_0}$	intensity level (dB)
$Z = \rho c$	acoustic impedance
$\alpha = \dfrac{I_r}{I_0} = \dfrac{(Z_2 - Z_1)^2}{(Z_2 + Z_1)^2}$	intensity reflection coefficient
$I = I_0 e^{-\mu x}$	transmitted intensity through a medium

List of data, formulae and relationships

A1.	$E = mc\Delta T$	energy transfer during heating and cooling
A2.	$E = l\,\Delta m$	energy transfer during change of state
A3.	$pV = nRT$	equation of state for an ideal gas
A4.	$pV = \frac{1}{3}Nm\overline{c^2}$	kinetic theory equation
A5.	$E_k = \frac{3RT}{2N_A}$	molecular kinetic energy
B1.	$F = m\frac{\Delta v}{\Delta t} = \frac{\Delta p}{\Delta t}$	force
B2.	moment = $F \times d$	moment of a force
B3.	$E_p = m\,g\,h$	gravitational potential energy
B4.	$E_k = \frac{1}{2}mv^2$	kinetic energy
B5.	$P = Fv$	mechanical power
B6.	$a = \frac{v^2}{r} = \omega^2 r$	centripetal acceleration
B7.	$F = \frac{Gm_1m_2}{r^2}$	Newton's law of gravitation
C1.	$\Delta y = \frac{\lambda D}{a}$	fringe width in double-slit interference
C2.	$d \sin\theta = n\lambda$	diffraction grating equation
C3.	$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$	equation for a single lens

D1.	$F = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$	Coulomb's law
D2.	$E = \frac{Q}{4\pi\varepsilon_0 r^2}$	electric field strength due to a point charge
D3.	$V = \frac{Q}{4\pi\varepsilon_0 r}$	electric potential due to a point charge
D4.	$E = \frac{V}{d}$	electric field between parallel plates (numerically)
D5.	$I = nAvQ$	general current flow equation
D6.	$R = \frac{\rho l}{A}$	resistance and resistivity
D7.	$R = R_1 + R_2$	resistors in series
D8.	$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$	resistors in parallel
D9.	$P = IV = I^2R$	power in a circuit
D10.	$F = BQv\sin\theta$	force on a moving charge in a magnetic field
D11.	$F = BIl\sin\theta$	force on a current-carrying conductor in a magnetic field
D12.	$V = \frac{BI}{nQt}$	Hall voltage
D13.	$B = \frac{\mu_0 I}{2\pi r}$	magnetic field due to a long straight wire
D14.	$B = \frac{\mu_0 NI}{l}$	magnetic field inside a long solenoid
D15.	$\varepsilon = N\frac{\Delta\Phi}{\Delta t}$	induced e.m.f.
D16.	$\frac{V_s}{V_p} \approx \frac{N_s}{N_p}$	ratio of secondary voltage to primary voltage in a transformer
E1.	$N = N_0 e^{-kt}$	law of radioactive decay
E2.	$t_{\frac{1}{2}} = \frac{\ln 2}{k}$	half-life and decay constant
E3.	$A = kN$	activity and the number of undecayed nuclei
E4.	$\Delta E = \Delta mc^2$	mass-energy relationship

Use the following data wherever necessary :

Atomic mass unit	$u = 1.661 \times 10^{-27}$ kg	(1 u is equivalent to 931 MeV)
Speed of light in vacuum	$c = 3.00 \times 10^{8}$ m s^{-1}	
Charge of electron	$e = 1.6 \times 10^{-19}$ C	

The following list of formulae may be found useful :

Law of radioactive decay	$N = N_0 e^{-kt}$
Half-life and decay constant	$t_{\frac{1}{2}} = \dfrac{\ln 2}{k}$
Activity and the number of undecayed nuclei	$A = kN$
Mass-energy relationship	$\Delta E = \Delta m c^2$

Part A :

The following questions marked with { } are the past DSE examination questions.
The question marked with {SP} is the Sample Paper question.
The question marked with {PP} is the Practice Paper question.
The number inside the brackets represents the year of the DSE examination.

M1. Which of these is a nuclear fusion reaction ?

{SP} A. $^{235}_{92}\text{U} + \text{n} \longrightarrow {}^{144}_{56}\text{Ba} + {}^{90}_{36}\text{Kr} + 2\,\text{n}$

B. $^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \longrightarrow {}^{4}_{2}\text{He} + \text{n}$

C. $^{14}_{7}\text{N} + \text{n} \longrightarrow {}^{14}_{6}\text{C} + {}^{1}_{1}\text{H}$

D. $^{238}_{92}\text{U} \longrightarrow {}^{234}_{90}\text{Th} + \alpha$

M2. For the following nuclear reaction, state the type of reaction and determine the energy released.

{PP} $^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \longrightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n}$

Given : mass of $^{2}_{1}\text{H}$ = 2.014 u

mass of $^{3}_{1}\text{H}$ = 3.016 u

mass of $^{4}_{2}\text{He}$ = 4.003 u

mass of $^{1}_{0}\text{n}$ = 1.009 u

	Type of reaction	Energy released
A.	fusion	0.018 MeV
B.	fusion	16.76 MeV
C.	fission	0.018 MeV
D.	fission	16.76 MeV

M3. The sun releases huge amount of energy through thermonuclear fusion while at the same time its mass decreases. The {13} average power released by the sun is about 3.8×10^{26} W. Estimate the decrease in mass of the sun in one second.

A. 4.2×10^{6} kg
B. 4.2×10^{9} kg
C. 1.3×10^{15} kg
D. 1.3×10^{18} kg

M4. A radium nucleus decays to a radon nucleus by emitting an α-particle. The energy released in the process is 4.9 MeV. {14} Compared to the mass of a radium nucleus, the total mass of a radon nucleus and an α-particle is

A. 5.4×10^{-11} kg less.
B. 5.4×10^{-11} kg more.
C. 8.7×10^{-30} kg less.
D. 8.7×10^{-30} kg more.

M5. Which of the following nuclear reactions is/are spontaneous reaction(s) ?
{15} (1) ${}^{24}_{11}\mathrm{Na} \rightarrow {}^{24}_{12}\mathrm{Mg} + {}^{0}_{1}\mathrm{e}$
(2) ${}^{10}_{5}\mathrm{B} + {}^{1}_{0}\mathrm{n} \rightarrow {}^{7}_{3}\mathrm{Li} + {}^{4}_{2}\mathrm{He}$
(3) ${}^{2}_{1}\mathrm{H} + {}^{3}_{1}\mathrm{H} \rightarrow {}^{4}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{n}$

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

Part B :

The following questions marked with ( ) are the past HKCE questions.

The number inside the brackets represents the year of the examination.

M6. In the following nuclear reaction :
(83) $${}^{27}_{13}\mathrm{Al} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{30}_{15}\mathrm{P} + X$$
what is the mass number and atomic number of X ?

	Mass number	Atomic number
A.	1	0
B.	0	−1
C.	4	2
D.	0	0

M7. Which of the following equations represent(s) possible nuclear reactions ?
(86) (1) ${}^{10}_{5}\mathrm{B}$ + neutron $\longrightarrow$ ${}^{6}_{3}\mathrm{Li}$ + α particle
(2) ${}^{210}_{83}\mathrm{Bi} \longrightarrow {}^{210}_{84}\mathrm{Po}$ + β particle
(3) ${}^{14}_{7}\mathrm{N}$ + α particle $\longrightarrow$ ${}^{17}_{8}\mathrm{O}$ + proton

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

M8. Which of the following equations represents(s) possible nuclear reaction(s) ?

(91) (1) $^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \longrightarrow ^{30}_{15}\text{P}$ + proton

(2) $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \longrightarrow ^{4}_{2}\text{He}$ + neutron

(3) $^{234}_{90}\text{Th} \longrightarrow ^{234}_{91}\text{Pa}$ + β particle

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

M9.
(93) $$^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \longrightarrow ^{30}_{15}\text{P} + X$$

In the above nuclear reaction, what are the atomic number and mass number of X ?

	Atomic number	Mass number
A.	−1	0
B.	−1	1
C.	0	1
D.	1	0

M10. In the below nuclear reactions, what do X, Y and Z represent ?

(96) (1) $^{210}_{84}\text{Po} \longrightarrow ^{206}_{82}\text{Pb} + X$

(2) $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \longrightarrow ^{4}_{2}\text{He} + Y$

(3) $^{234}_{90}\text{Th} \longrightarrow ^{234}_{91}\text{Pa} + Z$

	X	Y	Z
A.	an α particle	a proton	a β particle
B.	an α particle	a neutron	a β particle
C.	an α particle	a neutron	γ rays
D.	a β particle	a neutron	γ rays

M11.
(04) $$^{2}_{1}\text{H} + ^{x}_{1}\text{H} \rightarrow ^{4}_{y}\text{Z} + \text{a neutron}$$

Find the values of x and y in the above nuclear reaction.

	x	y
A.	2	1
B.	2	2
C.	3	1
D.	3	2

M12. Which of the following nuclear reactions is a nuclear fusion ?

(05) A. $^{235}_{92}U + n \longrightarrow ^{144}_{56}Ba + ^{90}_{36}Kr + 2n$

B. $^{14}_{7}N + n \longrightarrow ^{14}_{6}C + ^{1}_{1}H$

C. $^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + n$

D. $^{238}_{92}U \longrightarrow ^{234}_{90}Th + \alpha$

M13. Which of the following nuclear reactions is a fission ?

(08) A. $^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{144}_{56}BA + ^{89}_{36}Kr + 3\,^{1}_{0}n$

B. $^{238}_{92}U + ^{1}_{0}n \longrightarrow ^{239}_{94}Pu + 2\,^{0}_{-1}e$

C. $^{238}_{92}U + ^{14}_{7}N \longrightarrow ^{248}_{99}Es + 4\,^{1}_{0}n$

D. $^{2}_{1}H + ^{3}_{1}H \longrightarrow ^{4}_{2}He + ^{1}_{0}n$

M14. Which of the following conditions is/are necessary to sustain the chain reaction in the nuclear fission of uranium-235 ?
(09) (1) Each fission produces a large amount of energy.
(2) At least one neutron is released in each fission.
(3) Each fission produces two smaller nuclei.

A. (1) only
B. (2) only
C. (1) & (3) only
D. (2) & (3) only

M15.
(09) $^{2}_{1}H + ^{3}_{1}H \rightarrow ^{4}_{2}He + n$

Which of the following descriptions about the nuclear reaction above is correct ?

A. It is a nuclear fission.
B. It is a nuclear fusion.
C. It is a chain reaction.
D. It is a radioactive decay.

Part C :

The following questions marked with [ ] are the past HKAL questions.

The number inside the brackets represents the year of the examination.

M16. Which of the following equations represent possible reactions ?

[80] (1) $^{10}_{5}B$ + neutron $\longrightarrow ^{6}_{3}Li + ^{4}_{2}He$

(2) $^{210}_{83}Bi \longrightarrow ^{210}_{84}Po$ + beta particle

(3) $^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O$ + proton

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M17. $^{14}_{7}N$ + alpha particle $\longrightarrow$ proton + X

[92] In the above nuclear reaction, X is

A. $^{17}_{8}O$

B. $^{17}_{9}F$

C. $^{17}_{7}N$

D. $^{11}_{6}C$

M18. The main reason why a chain reaction can occur in a nuclear reactor using uranium is that

[92] A. a large quantity of energy is evolved in each fission.

B. the products of nuclear fission are highly radioactive.

C. plutonium is produced and it undergoes further fission.

D. neutrons are produced when a nucleus undergoes fission.

M19. The sun and stars generate their energy mainly by

[03] (1) radioactive decay.

(2) nuclear fission.

(3) nuclear fusion.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M20. The following nuclear reaction represents the two deuterons, $^{2}_{1}H$, which combine to form a helium isotope, $^{3}_{2}He$, with the

[04] release of energy.

$$2\,^{2}_{1}H \rightarrow \,^{3}_{2}He + X + \text{energy}$$

Which of the following statements are correct ?

(1) This is an example of nuclear fusion.

(2) The total mass of $^{3}_{2}He$ and X is greater than that of the two $^{2}_{1}H$.

(3) X is a neutron.

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

M21. The following equation represents a nuclear fission reaction, producing q neutrons.

[05] $$^{235}_{92}U + \,^{1}_{0}n \longrightarrow \,^{141}_{56}Ba + \,^{92}_{Z}Kr + q\,^{1}_{0}n$$

What are the values of the atomic number Z and the number q ?

	Z	q
A.	37	2
B.	36	2
C.	36	3
D.	34	3

M22. Which nuclear reactions are accompanied with a mass defect ?

[12] (1) the union of hydrogen isotopes to form helium

$${}^{2}_{1}\text{H} + {}^{3}_{1}\text{H} \longrightarrow {}^{4}_{2}\text{He} + {}^{1}_{0}\text{n}$$

(2) the natural radioactive decay of radium-226

$${}^{226}_{88}\text{Ra} \longrightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\text{He}$$

(3) the emission of a β-particle from a nucleus

$${}^{1}_{0}\text{n} \longrightarrow {}^{1}_{1}\text{H} + {}^{0}_{-1}\text{e}$$

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

M23. Assume that the sun radiates energy at a constant rate of 4.0×10^{26} W by a thermonuclear fusion process. The mass of the
[13] sun is 2.0×10^{30} kg. Estimate the lifetime of the sun if 0.07% of its mass is converted into radiation during the sun's lifetime.

Given : 1 year = 3.15×10^{7} s

A. 1.0×10^{6} years
B. 1.0×10^{10} years
C. 1.0×10^{12} years
D. 1.0×10^{17} years

Part D :

The following questions are designed to give supplemental exercise for this chapter.

M24. In which type of nuclear reaction are the nuclei heavier after the reaction than they were before ?
A. α-decay
B. β-decay
C. γ-emission
D. nuclear fusion

M25. A worker at a nuclear plant walks into a room and is accidentally exposed to a small amount of radiation. The worker will
A. lose consciousness.
B. feel very hot.
C. feel painful.
D. feel no effect.

M26. In the Sun, energy is released when hydrogen nuclei collide and form heavier nuclei. This process is called
A. diffusion.
B. fission.
C. fusion.
D. ionization.

M27. In a particular chain reaction, a neutron collides with a heavy nucleus. The nucleus then splits to give two lighter nuclei, energy and

A. alpha particles.
B. beta particles.
C. protons.
D. neutrons.

M28. Which of the following show(s) nuclear fission ?

(1) ${}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{141}_{56}Ba + {}^{92}_{36}Kr + 3\,{}^{1}_{0}n$

(2) ${}^{241}_{94}Pu \longrightarrow {}^{237}_{92}U + {}^{4}_{2}He$

(3) ${}^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{4}_{2}He$

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M29. A U-235 nucleus will split when it captures

A. an alpha particle.
B. a beta particle.
C. a neutron.
D. a proton.

M30. The Sun releases its energy mainly by

(1) radioactive decay.
(2) nuclear fission.
(3) nuclear fusion.

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M31. The following equations represent some typical nuclear reactions :

(I) ${}^{9}_{4}Be + {}^{1}_{1}H \longrightarrow {}^{6}_{3}Li + {}^{4}_{2}He$

(II) ${}^{2}_{1}H + {}^{3}_{1}H \longrightarrow {}^{4}_{2}He + {}^{1}_{0}n$

(III) ${}^{235}_{92}U + {}^{1}_{0}n \longrightarrow {}^{148}_{57}La + {}^{85}_{35}Br + 3\,{}^{1}_{0}n$

Which of the following descriptions of these reactions is/are correct ?

(1) Reaction (I) represents an α-decay.
(2) Reaction (II) represents a nuclear fusion.
(3) Reaction (III) represents a nuclear fission.

A. (1) only
B. (1) & (2) only
C. (2) & (3) only
D. (1), (2) & (3)

M32. The main reason why a chain reaction can occur in a nuclear reactor using uranium is that

A. a large amount of energy is released in each fission.

B. the products of nuclear fission are highly radioactive.

C. uranium splits into two smaller fragments.

D. fission neutrons are produced

M33. If there were accident in a nearby nuclear power plant, which of the following is NOT the way that the radioactive substances released in the accident can spread to the neighbouring lands ?

A. By wind

B. By rain water

C. By animals

D. By plants

M34. Which of the following is NOT the disadvantage of using nuclear energy ?

A. The capital investment of a nuclear power plant is very large.

B. There must be leakage of radiation in a nuclear power plant.

C. Once accident occurs, it would be very serious.

D. The disposal of radioactive waste is a difficult problem.

M35. Which of the following do(es) NOT make use of nuclear fusion ?

(1) A nuclear bomb

(2) A hydrogen bomb

(3) Emission of light by a star

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M36. Which of the followings are the advantages of using nuclear energy ?

(1) Nuclear energy causes less pollution to our environment.

(2) The running cost of power plant using nuclear energy is lower.

(3) Nuclear energy is the only choice other than the use of fossil fuel.

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

M37. Which of the following are the advantages of using nuclear fusion to generate electricity ?

(1) The fuel for nuclear fusion is hydrogen which has unlimited supply in oceans.

(2) The waste products in nuclear fusion are not radioactive.

(3) The nuclear fusion takes place at a very high temperature.

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

M38. Which of the following are the difficulties to use nuclear fusion for generating electricity ?

(1) Nuclear fusion can only take place at a very high temperature.

(2) No physical container can withstand the high temperature that fusion occurs.

(3) It is difficult to dispose the waste products of the fusion.

A. (1) & (2) only
B. (1) & (3) only
C. (2) & (3) only
D. (1), (2) & (3)

M39. Which of the following nuclear reactions is/are an example of fusion ?

(1) $^{226}_{88}Ra \longrightarrow {}^{222}_{86}N + {}^{4}_{2}He + \text{energy}$

(2) $^{14}_{6}C \longrightarrow {}^{14}_{7}N + {}^{0}_{-1}e + \text{energy}$

(3) $^{2}_{1}H + {}^{2}_{1}H \longrightarrow {}^{3}_{2}He + {}^{1}_{0}n + \text{energy}$

A. (1) only
B. (3) only
C. (1) & (2) only
D. (2) & (3) only

M40. Which of the following nuclear reactions is an example of fusion ?

A. Carbon-14 decaying to nitrogen and an electron

B. Two heavy hydrogen nuclei becoming helium and a neutron

C. Radium-226 decaying to radon-222 and an alpha particle

D. Sodium-24 decaying to magnesium-24 and a beta particle

M41. In the following nuclear decay :

$$^{24}_{11}Na \longrightarrow {}^{24}_{12}Mg + {}^{0}_{-1}\beta$$

Given the data below :

mass of $^{24}_{11}Na$ = 23.99096 u

mass of $^{24}_{12}Mg$ = 23.98504 u

energy released in the decay = 5.00216 MeV

Calculate the rest mass of the beta particle released.

A. 0.00025 u

B. 0.00055 u

C. 0.00085 u

D. 0.00952 u

Answers

1. B	11. D	21. C	31. C	41. B
2. B	12. C	22. D	32. D	
3. B	13. A	23. B	33. D	
4. C	14. B	24. D	34. B	
5. A	15. B	25. D	35. A	
6. A	16. D	26. C	36. A	
7. D	17. A	27. D	37. A	
8. D	18. D	28. A	38. A	
9. C	19. B	29. C	39. B	
10. B	20. B	30. B	40. B	

Solution

1. B

× A. This is an example of nuclear fission.

✓ B. Fusion is the combination of two smaller nuclei : H-2 and H-3 to form a larger nucleus : He-4.

× C. This is an example of bombardment of particle into a nucleus.

× D. This is an example of alpha decay.

2. B

Since the reaction is to combine two hydrogen nuclei into a helium nucleus, it is a fusion reaction.

Mass defect $= 2.014 + 3.016 - 4.003 - 1.009 = 0.018$ u

Energy released $= 0018 \times 931 = 16.76$ MeV

3. B

In 1 second, energy released is 3.8×10^{26} J.

By $\Delta E = \Delta m\, c^2$

$\therefore\ (3.8 \times 10^{26}) = \Delta m\,(3 \times 10^8)^2 \quad \therefore\ \Delta m = 4.2 \times 10^9$ kg

4. C

By Einstein's equation :

$\Delta E = \Delta m\, c^2$

$\therefore\ (4.9 \times 10^6 \times 1.6 \times 10^{-19}) = \Delta m \times (3 \times 10^8)^2 \qquad \therefore\ \Delta m = 8.7 \times 10^{-30}$ kg

Since energy is released, there is mass defect.

Thus, the total mass of the daughter nucleus Y and α-particle is less than the mother nucleus.

5. A

✓ (1) This is a beta-decay reaction, which is spontaneous.

× (2) This is a bombardment reaction, triggered by the hitting of neutron onto the nucleus B-10.

× (3) This is a fusion reaction, which occurs when the temperature is high enough.

6. A

$^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \rightarrow ^{30}_{15}\text{P} + ^{1}_{0}X$

Mass number $= 1$ Atomic number $= 0$

7. D

× (1) $^{10}_{5}\text{B} + ^{1}_{0}n \rightarrow ^{6}_{3}\text{Li} + ^{4}_{2}\text{He}$ Mass number is not balanced.

✓ (2) $^{210}_{83}\text{Bi} \rightarrow ^{210}_{84}\text{Po} + ^{0}_{-1}e$ Both mass number and atomic number are balanced.

✓ (3) $^{14}_{7}\text{N} + ^{4}_{2}\text{He} \rightarrow ^{17}_{8}\text{O} + ^{1}_{1}p$ Both mass number and atomic number are balanced.

8. D

× (1) $^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \rightarrow ^{30}_{15}\text{P} + ^{1}_{1}p$ Atomic number is not balanced.

✓ (2) $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{1}_{0}n$ Both mass number and atomic number are balanced.

✓ (3) $^{231}_{90}\text{Th} \rightarrow ^{231}_{91}\text{Pa} + ^{0}_{-1}e$ Both mass number and atomic number are balanced.

9. C

Balancing the equation, $^{27}_{13}\text{Al} + ^{4}_{2}\text{He} \rightarrow ^{30}_{15}\text{P} + ^{1}_{0}X$

Atomic number $= 0$ Mass number $= 1$

10. B

(1) $^{210}_{84}\text{Po} \rightarrow ^{206}_{82}\text{Pb} + ^{4}_{2}\text{He}$ X: α particle

(2) $^{2}_{1}\text{H} + ^{3}_{1}\text{H} \rightarrow ^{4}_{2}\text{He} + ^{1}_{0}n$ Y: neutron

(3) $^{234}_{90}\text{Th} \rightarrow ^{234}_{91}\text{Pa} + ^{0}_{-1}e$ Z: β particle

11. D

The symbol of neutron is $^{1}_{0}\text{n}$

Balance the mass number : $2 + x = 4 + 1$ $\therefore x = 3$

Balance the atomic number : $1 + 1 = y + 0$ $\therefore y = 2$

12. C

× A. This is an example of nuclear fission.

× B. This is an example of bombardment of particle into a nucleus.

✓ C. Fusion is the combination of two smaller nuclei : H-2 and H-3 to form a larger nucleus : He-4.

× D. This is an example of alpha decay.

13. A

✓ A. It is a typical fission of U-235, triggered by a neutron.

× B. It is a bombardment of particle reaction.

× C. It is a bombardment of particle reaction.

× D. It is a fusion.

14. B

× (1) Fission would produce a large amount of energy, but the energy cannot sustain the chain reaction.

✓ (2) In each fission, neutrons are produced and these neutrons can trigger the further fission of U-235, thus the chain reaction can be sustained.

× (3) Fission produces two smaller nuclei, but these smaller nuclei cannot sustain the further fission.

15. B

As the reaction involves the combination of H-2 and H-3 to become He-4,
it is a fusion reaction.

16. D

× (1) ${}^{10}_{5}\mathrm{B} + {}^{1}_{0}n \rightarrow {}^{6}_{3}\mathrm{Li} + {}^{4}_{2}\mathrm{He}$ Mass number is not conserved.

✓ (2) ${}^{210}_{83}\mathrm{Bi} \rightarrow {}^{210}_{84}\mathrm{Po} + {}^{0}_{-1}e$ Both mass number and charge are conserved.

✓ (3) ${}^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{17}_{8}\mathrm{O} + {}^{1}_{1}p$ Both mass number and charge are conserved.

17. A

Balancing the mass number and atomic number : ${}^{14}_{7}\mathrm{N} + {}^{4}_{2}\mathrm{He} \rightarrow {}^{1}_{1}p + {}^{17}_{8}\mathrm{O}$.

18. D

Neutrons can trigger the further fissions of the remaining U-235 nuclei, thus maintain the chain reaction

19. B

× (1) The energy released in decay is negligible compared with that in nuclear fission or fusion.

× (2) Nuclear fission occurs for element of very high atomic number.
The sun and stars do not contain these elements.

✓ (3) The sun and stars contain mainly hydrogen and helium for nuclear fusion to take place.

20. B

✓ (1) Small nuclei ${}^{2}_{1}\mathrm{H}$ combining to form large nuclei ${}^{3}_{2}\mathrm{He}$ is a fusion process.

× (2) Since energy is released, there must be mass defect. Thus the total mass of the product should be smaller.

✓ (3) $2\,{}^{2}_{1}\mathrm{H}$ □ ${}^{3}_{2}\mathrm{He} + {}^{1}_{0}\mathrm{X}$ $\therefore$ X is a neutron.

21. C

① $235 + 1 = 141 + 92 + q$

② $92 + 0 = 56 + z + 0$

$\therefore z = 36$ and $q = 3$

22. D

✓ (1) Since energy is released in this nuclear fusion, thus there is mass defect.

✓ (2) Since energy is released and becomes the kinetic energy of α-particle, there is mass defect.

✓ (3) Since energy is released and becomes the kinetic energy of β-particle, there is mass defect.

23. B

$E = m c^2 = (2.0 \times 10^{30} \times 0.07\%) \times (3 \times 10^8)^2 = 1.26 \times 10^{44}$ J

$E = P t$

$\therefore (1.26 \times 10^{44}) = (4.0 \times 10^{26})\, t$

$\therefore t = 3.15 \times 10^{17}$ s $= 1 \times 10^{10}$ years

24. D

× A. After α-decay, the daughter nucleus has its mass number decreased by 4.

× B. After β-decay, the daughter nucleus has its mass slightly decreased.

× C. After γ-emission, the mass of the nucleus is unchanged since γ has no mass.

✓ D. After nuclear fusion, the nucleus is heavier since it consists of smaller nuclei combining together.

25. D

There is no immediate effect on a worker who is exposed to small amount of radiation.

However, the radiation is accumulative in the human body and thus increases the chance of cancer in the future.

26. C

The Sun makes use of nuclear fusion to give out solar energy.

27. D

After nuclear fission, 2, 3 or 4 fission neutrons may be produced to cause further fission, thus give the chain reaction.

28. A

✓ (1) It is a typical fission of U-235.

× (2) It is an α-decay.

× (3) It is fusion.

29. C

When a neutron is captured by a U-235 nucleus, the neutron will trigger the fission of the uranium nucleus.

30. B

- × (1) The Sun does not contain radioactive nuclei to give radioactive decay.
- × (2) The Sun does not contain large nuclei to give fission.
- ✓ (3) The Sun contains mainly hydrogen that undergoes fusion to give out solar energy.

31. C

- × (1) Reaction (1) is the bombardment of proton on the Be-9 nucleus to give two other nuclei.
- ✓ (2) The combination of two smaller nuclei to give a large nucleus is called fusion.
- ✓ (3) The split up of a large nucleus to give two smaller nuclei is called fission.

32. D

The fission neutrons can trigger further fissions of the remaining uranium nuclei to give the chain reaction.

33. D

- ✓ A. Wind can carry the radioactive waste from one place to another place.
- ✓ B. Rain water can carry the radioactive waste from one place to flow to another place.
- ✓ C. Animals can bring the radioactive waste and move to another place.
- × D. Since plants cannot move, they cannot carry radioactive waste from one place to another place.

34. B

- ✓ A. Building a nuclear power plant is very expensive to ensure every safety measure.
- × B. A good design of nuclear power plant ensures no leakage of radiation to the environment.
- ✓ C. If explosion occurs in a nuclear power plant, it would cause disastrous effect to the environment.
- ✓ D. Since the wastes of fission product are radioactive, their disposal causes a series problem.

35. A

- ✓ (1) A nuclear bomb makes use of nuclear fission, NOT nuclear fusion.
- × (2) A hydrogen bomb indeed makes use of nuclear fusion of hydrogen to give out energy.
- × (3) A star, likes the Sun, makes use of nuclear fusion to give out energy.

36. A

- ✓ (1) Nuclear energy makes use of fission does not produce air pollution.
- ✓ (2) Nuclear energy is cheaper once the chain reaction starts.
- × (3) Other than the fossil fuels, there are renewable energy resources
  such as solar energy, wind energy and hydroelectric energy.

37. A

✓ (1) In ocean, there is unlimited supply of water that consists of hydrogen.

✓ (2) The water products in nuclear fusion are helium which are noble gas and not radioactive.

✗ (3) Fusion takes place at high temperature is a disadvantage, not advantage.

38. A

✓ (1) Nuclear fusion takes place at very high temperature; it is not easy to produce such a high temperature.

✓ (2) Even the high temperature (about 10 000 000°C) is achieved, all containers will change to gases.

✗ (3) The waste products of fusion is clean and not radioactive, and thus no disposal problem.

39. B

✗ (1) It is an example of α-decay.

✗ (2) It is an example of β-decay.

✓ (3) It is an example of nuclear fusion.

40. B

Fusion is combining two smaller nuclei (the hydrogen) to form a large nucleus (the helium).

41. B

As 1 u is equivalent to 931 MeV,

mass equivalent of the energy released $= \dfrac{5.00216}{931} = 0.00537$ u

By conservation of mass and energy,

$23.99096 = 23.98504 + m_\beta + 0.005373$

$\therefore\ m_\beta = 0.00055$ u

Use the following data wherever necessary :

Speed of light in vacuum	$c = 3 \times 10^8$ m s^{-1}
Charge of an electron	$e = 1.60 \times 10^{-19}$ C
Avogadro constant	$N_A = 6.02 \times 10^{23}$ mol^{-1}
Atomic mass unit	u = 1.661×10^{-27} kg (1 u is equivalent to 931 MeV)

The following list of formulae may be found useful :

Half-life and decay constant	$t_{\frac{1}{2}} = \dfrac{\ln 2}{k}$
Activity and the number of undecayed nuclei	$A = kN$
Mass-energy relationship	$\Delta E = \Delta m\, c^2$

Part A :

The following questions marked with { } are the past DSE examination questions.

The question marked with {SP} is the Sample Paper question.

The number inside the brackets represents the year of the DSE examination.

Q1. {SP} In April 1986, a disastrous nuclear accident happened at the Chernobyl Nuclear Power Station. A large quantity of various radioactive substances was released and spread to neighbouring countries. The radiation levels recorded in these countries were much higher than the normal background radiation count rate.

(a) State ONE source of background radiation.

____

(b) One of the radioactive isotopes released in the accident was caesium-137 (Cs-137). The following equation shows how Cs-137 is produced :

$$^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \longrightarrow {}^{137}_{55}\text{Cs} + {}^{95}_{37}\text{Rb} + x\,{}^{1}_{0}\text{n}$$

Given : mass of one nuclide of $^{235}_{92}$U = 235.0439 u

$^{137}_{55}$Cs = 136.9071u

$^{95}_{37}$Rb = 94.9399 u

$^{1}_{0}$n = 1.0087 u.

(i) What is the value of x ? (1 mark)

____

____

(ii) Find the energy release in the fission of one U-235 nuclide in MeV. (2 marks)

____

____

____

____

Q1. (b) (iii) The half-life of Cs-137 is 30 years. A soil sample contaminated by Cs-137 has an activity of 1.2×10^6 Bq (disintegration per second). A physicist comments that the contaminated sample will affect the environment for more than 350 years. Justify the physicist's claim with calculations. It is known that the activity of an uncontaminated soil sample is 200 Bq. (2 marks)

Q2. Radium-226 ($^{226}_{88}Ra$) undergoes α-decay into radon (Rn).
{12}

(a) Write a nuclear equation for the decay. (2 marks)

(b) Given : mass of a radium nucleus = 226.0254 u
mass of a radon nucleus = 222.0176 u
mass of an α-particle = 4.0026 u

Calculate the energy released in the decay in MeV. (2 marks)

(c) 1 curie (Ci) is defined as the activity of 1 g of radium. The activity of a radium source used in laboratories is about 5 μCi. Estimate the number of radium atoms in this source and hence find its activity expressed in disintegrations per second. The half-life of radium-226 is 1600 years and take the mass of one mole of radium as 226 g.
(1 μCi = 1×10^{-6} Ci) (3 marks)

Q3. {15} Scientists had been experimenting controlled fusion in a nuclear reactor in which deuterium ($^2_1$H) and tritium ($^3_1$H) undergo the following nuclear fusion :

$$^2_1\text{H} + {}^3_1\text{H} \rightarrow {}^4_2\text{He} + {}^1_0\text{n} + \text{energy released}$$

Given : mass of a deuterium nucleus = 2.014102 u
mass of a tritium nucleus = 3.016049 u
mass of a helium nucleus = 4.002602 u
mass of a neutron = 1.008665 u

(a) Calculate the energy released, in MeV, in the above nuclear fusion. (2 marks)

(b) In the nuclear reactor, deuterium and tritium exist as plasma, which is a mixture of ions at a very high temperature. To start the fusion reaction, the average kinetic energy of the ions in the plasma has to reach the minimum value of 0.2 MeV.

(i) Explain why a very high temperature is needed for nuclear fusion to occur. (2 marks)

(ii) Estimate the order of magnitude of the minimum temperature at which fusion of deuterium and tritium nuclei would be possible if the plasma can be regarded as an ideal gas. (2 marks)

Part B :

The following question marked with ( ) is the past HKCE question.

The number inside the bracket represents the year of the examination.

Q4. (03) In 1986, a disastrous nuclear accident happened at the Chernobyl Nuclear Station. A large amount of radioactive substance was released and spread to neighbouring countries. The radiation levels recorded in these countries were much higher than the normal background count rate.

(a) State two sources of background radiation. (2 marks)

(b) State one way by which the radioactive substances released in the accident were spread to neighbouring countries. (1 mark)

(c) One of the radioactive isotopes released in the accident was caesium-137 (Cs-137). The following equation shows how Cs-137 is produced :

$$^{235}_{92}\mathrm{U} + ^{1}_{0}\mathrm{n} \longrightarrow ^{137}_{x}\mathrm{Cs} + ^{y}_{37}\mathrm{Rb} + z\,^{1}_{0}\mathrm{n}$$

(i) If $z = 4$, find the values of x and y and state their physical meanings. (4 marks)

(ii) The half-life of Cs-137 is 30 years. Suppose that a soil sample contaminated by Cs-137 is 30 years was found to have an initial activity of 1.2×10^6 Bq (disintegrations per second). A physicist comments that the contaminated sample will affect the environment for more than 300 years. Justify the physicist's claim with calculations. You may assume that the activity of a non-contaminated sample of similar nature is 200 Bq. (3 marks)

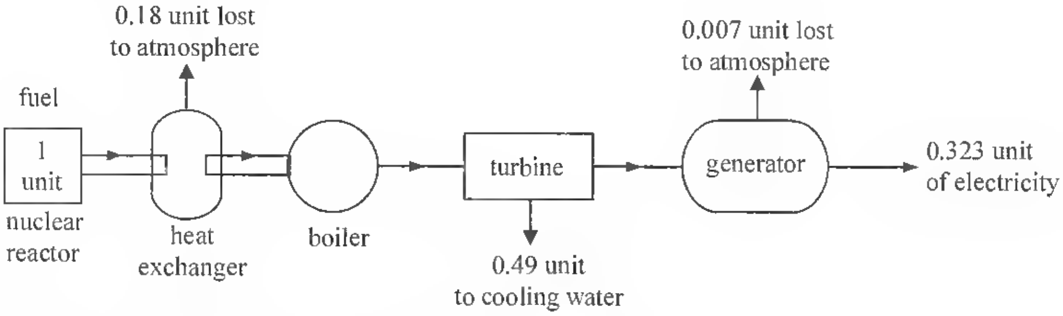
(d) The development of nuclear energy is a controversial issue. Do you support the development of nuclear energy ? State the reasoning to support your point of view. (4 marks)

Part C :

The following questions marked with [ ] are the past HKAL questions.

The number inside the brackets represents the year of the examination.

Q5.
[83]



The figure above shows what happens to one unit of energy produced in the nuclear reactor of a nuclear power plant.

(a) Suppose the electrical power output of this plant is 1066 MW, calculate

(i) the total power generated by the reactor, (1 mark)

(ii) the power lost to the atmosphere. (1 mark)

(b) The turbine is cooled by circulating water through it at the rate of 48 $m^3\ s^{-1}$. Calculate the rise in temperature of the cooling water. (Density of water = 10^3 kg m^{-3}, specific heat capacity of water = 4200 J kg^{-1} K^{-1}) (3 marks)

(c) In the reactor, energy is produced by the fission of uranium-235 atoms.

$$^{235}U + n \longrightarrow {}^{141}Ba + {}^{92}Kr + 3n$$

Masses of the above nuclides are : ^{235}U = 235.0409 u
^{141}Ba = 140.9141u
^{92}Kr = 91.9250 u
n = 1.0086 u.

Calculate the number of uranium atoms which undergo fission in 1 s. (3 marks)

(d) The nuclear plant is designed to produce power continuously for 10 years without refuelling. Estimate the mass of uranium-235 that will be consumed in this time, assuming that only the above reaction takes place. Given that the mass of 1 mole of U-235 is 235 g. (2 marks)

Q6. The following equation represents a possible nuclear reaction in a fission reactor :

[93] $$^{235}_{92}U + ^{1}_{0}n \longrightarrow ^{91}_{36}Kr + ^{142}_{56}Ba + 3\,^{1}_{0}n$$

Given : the mass of one nucleus of $^{235}_{92}U$ = 235.0439 u

$^{91}_{36}Kr$ = 90.9234 u

$^{142}_{56}Ba$ = 141.9164 u

$^{1}_{0}n$ = 1.0087 u

(a) According to the above equation, what is the mass defect between the reactants and products when one $^{235}_{92}U$ nucleus undergoes fission ? (2 marks)

(b) If 4.00×10^{-5} kg of $^{235}_{92}U$ splits per second, calculate the rate of energy production. Take the mass of one mole of $^{235}_{92}U$ as 235 g. (3 marks)

Q7. A reaction which takes place in the core of a nuclear reactor is described by the following equation :

[98] $$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{142}_{56}Ba + ^{91}_{36}Kr + 3\,^{1}_{0}n + 173.8 \text{ MeV}$$

Mass of one nuclide of $^{235}_{92}U$ = 235.0439 u

Mass of one nuclide of $^{142}_{56}Ba$ = 141.9164 u

Mass of one nuclide of $^{91}_{36}Kr$ = 90.9234 u

(a) Calculate the mass, in atomic mass unit, of a neutron. (3 marks)

(b) The fuel rods in the reactor contain 1.0×10^{4} kg of U-235 isotope. Calculate the total energy released from the complete fission of all the U-235 nuclei in the fuel rods. Take the mass of one mole of U-235 as 235 g. (3 marks)

(c) If the mean power output of the reactor is 500 MW and the efficiency of conversion of nuclear energy to electrical energy is 40%, estimate the time for which the fuel rods can be used. (2 marks)

Q8. The energy released by the Sun is the result of thermonuclear fusion in its core, where hydrogen are fused together into
[02] helium nuclei through a complicated process. The overall reaction can be represented by the following equation :

$$4\,{}^{1}_{1}\text{H} \longrightarrow {}^{4}_{2}\text{He} + \text{other particles of negligible mass} + \text{energy}$$

(a) Why is the above process of forming helium nuclei from protons very difficult to achieve on Earth, but easily achieved at the Sun's core ? (2 marks)

(b) Given : mass of hydrogen = 1.00728 u

mass of helium = 4.00150 u

Calculate the energy released in each fusion by the Sun. Express your answer in joule. (2 marks)

(c) Calculate the total energy released by the Sun for every kilogram of hydrogen fused to form helium nuclei. Take the mass of one mole of hydrogen be 1 g. (2 marks)

Q9. A nucleus of radon (${}^{222}_{86}\text{Rn}$) decays to an isotope of polonium (Po) by emitting an α-particle.

[10] Given : mass of a radon nucleus = 222.0176 u

mass of a polonium nucleus = 218.0090 u

mass of an α-particle = 4.0026 u

(a) Write an equation for the decay and find the energy released, in MeV, in the decay. (3 marks)

(b) The energy released in the decay becomes the kinetic energy of the decay products. Explain quantitatively why the α-particle takes most of the energy. Assume that the parent nucleus is at rest initially. (2 marks)

(c) Hence calculate the speed v of the α-particle, assume all the decay energy is transferred to the α-particle. (2 marks)

Q10. Iodine-131 ($^{131}_{53}\mathrm{I}$) is a common radioactive nuclide found in radioactive waste from nuclear power plants. It undergoes
[12] β decay to a stable nuclide Xenon-131 ($^{131}\mathrm{Xe}$) with a half-life of 8.02 days.

(a) Write down the decay equation of Iodine-131. (1 mark)

(b) (i) Estimate the initial activity of 1 kg of Iodine-131 in Bq. (3 marks)

Given : mass of one mole of Iodine-131 = 131 g

(ii) Assuming that the mass loss of the decay of Iodine-131 becomes heat, estimate the initial heating power of 1 kg of Iodine-131 in the unit W. (4 marks)

Given : mass of an Iodine-131 nucleus = 130.90612 u

mass of a Xenon-131 nucleus = 130.90508 u

mass of an electron = 0.00054 u

(c) Even after a reactor is shut down and nuclear fission completely stopped, fission products like Iodine-131 keep on producing heat. Explain why we cannot stop the Iodine-131 from producing heat. (2 marks)

(d) Iodine-123 is another radioactive isotope of Iodine. It emits γ rays and has a half-life of 13 hours. As thyroid in the human body readily absorbs iodine, Iodine-123 is commonly used as a medical tracer for diagnosis of thyroid diseases. Give ONE reason why Iodine-123 is more suitable to be used as medical tracer than Iodine-131. (1 mark)

Part D :

The following questions are designed to give supplemental exercise for this chapter.

Q11. (a) When an alpha particle strikes a beryllium $\left({}^{9}_{4}\mathrm{Be}\right)$ nucleus, one carbon $\left({}^{12}_{6}\mathrm{C}\right)$ nucleus and one particle Q are formed. Write down the nuclear equation. What is the particle Q ? (3 marks)

(b) A nuclear power plant makes use of nuclear fission of uranium to generate electrical power at a rate of 500 MW. The internal energy that can be extracted from 1 kg of uranium fuel in the fission reactor is about 5.6×10^{12} J. The efficiency of energy conversion to electrical form in the nuclear reactor is only 30%. (1 MW = 10^6 W)

(i) What is the electrical energy supplied in one day ? (2 marks)

(ii) If electrical energy costs $0.9 for 1 kWh, how much does it cost for the electrical energy generated in one day ? (4 marks)

(iii) Calculate the electrical energy that can be produced by 1 kg of uranium in the fuel rod. (2 marks)

(iv) Find the mass of uranium fuel used in one day. (2 marks)

(c) Some people propose that nuclear energy should eventually replace oil and coal as sources of energy supply. Do you agree with this ? List 3 reasons to support your argument. (4 marks)

Q12. In a nuclear reactor for generating electricity, Uranium-235 undergoes fission to generate energy.

(a) Describe the process of nuclear fission of Uraniuim-235. (3 marks)

(b) The waste products from a nuclear reactor contain isotopes which are radioactive and emit β radiation. They are stored in sealed metal cans for 200 years until the activity decreases to 400 Bq that can be disposed of.

(i) Explain how these isotopes are produced. (2 marks)

(ii) What is meant by the term radioactive ? (2 marks)

(iii) State the reasons why metal cans are used to store the waste products. (1 mark)

(iv) It is known that the half life of the radioactive isotope in the metal cans is 25 years. What is the initial activity of the waste products in the cans ? (3 marks)

(v) Calculate the initial number of atoms of the radioactive isotope in the metal cans. (3 marks)

(c) David wonders why nuclear fusion is not used to generate electricity. Suggest two reasons to explain this. (2 marks)

Q1. (a) Any ONE of the following : [1]

- ✲ cosmic radiation from space
- ✲ radiation from rocks
- ✲ radiation from air
- ✲ radiation from food
- ✲ radiation from human bodies

(b) (i) $x = 4$ [1]

(ii) Mass defect $= 235.0439 - (136.9071 + 94.9399 + 3 \times 1.0087) = 0.1708$ u [1]

Energy released $= 0.1708 \times 931$ MeV $= 159$ MeV [1]

(iii) Activity of the sample after 350 years :

$A = (1.2 \times 10^6) \times e^{-(\frac{\ln 2}{30})\times(350)} = 369$ Bq

OR

$A = (1.2 \times 10^6) \times (\frac{1}{2})^{350/30} = 369$ Bq [1]

This activity is larger than 200 Bq. The sample will contaminate the environment for more than 350 years. [1]

Q2. (a) ${}^{226}_{88}\text{Ra} \rightarrow {}^{222}_{86}\text{Rn} + {}^{4}_{2}\alpha$ (**OR** ${}^{4}_{2}\text{He}$)

< atomic number and mass number of α correct > [1]

< atomic number and mass number of Rn correct > [1]

(b) Mass defect :

$\Delta m = 226.0254 - 222.0176 - 4.0026 = 0.0052$ u [1]

Energy released :

$E = 0.0052 \times 931 = 4.84$ MeV [1]

(c) Mass of radium $= 5$ μg

Number of radium atoms in this source :

$N = \dfrac{5\times10^{-6}}{226} \times 6.02 \times 10^{23} = 1.332 \times 10^{16}$ [1]

Decay constant :

$k = \dfrac{\ln 2}{t_{1/2}} = \dfrac{\ln 2}{1600\times365\times24\times3600} = 1.374 \times 10^{-11}\ \text{s}^{-1}$ [1]

Activity :

$A = kN = (1.374 \times 10^{-11}) \times (1.332 \times 10^{16}) = 1.83 \times 10^5$ disintegrations per second [1]

< accept 1.83×10^5 Bq > < accept 1.82×10^5 >

Q3. (a) $\Delta m = 2.014102 + 3.016049 - 4.002602 - 1.008665 = 0.018884$ u [1]

$E = 0.018884 \times 931 = 17.58$ MeV < accept 17.6 MeV > [1]

OR

$E = 0.018884 \times 1.661 \times 10^{-27} \times (3 \times 10^8)^2 = 2.823 \times 10^{-12}$ J [1]

(b) (i) To overcome the electrostatic repulsion between the two (positive) nuclei, [1]

the temperature must be very high so that the ions has sufficient kinetic energy to come close to each other. [1]

(ii) $E_k = \frac{3}{2} \cdot \frac{R}{N_A} \cdot T$

$\therefore\ (0.2 \times 10^6 \times 1.6 \times 10^{-19}) = \frac{3}{2} \cdot \frac{(8.31)}{(6.02 \times 10^{23})} \cdot T$ [1]

$\therefore\ T = 1.55 \times 10^9$ K

Order of magnitude of temperature $= 10^9$ K < exact answer not accepted > [1]

Q4. (a) Any **TWO** of the following : [2]

* Cosmic radiation from the space
* Radiation from rocks
* Radiation in air
* Radiation from food
* Radiation from our body

(b) Any **ONE** of the following : [1]

* by wind
* by rain
* by water in river
* by imported food

(c) (i) $x = 92 - 37 = 55$ [1]

$y = 235 + 1 - 137 - 4 = 95$ [1]

x is the atomic number of Cs [1]

y is the mass number of Rb [1]

(ii) Number of half-life in 300 years $= 10$ [1]

Activity after 10 half-lives $= (1.2 \times 10^6) \times (\frac{1}{2})^{10} = 1172$ Bq [1]

After 300 years, the activity is still higher than that of non-contaminated sample, thus his claim is correct. [1]

OR

By $(200) = (1.2 \times 10^6) \times (\frac{1}{2})^{t/30}$ [1]

$\therefore\ t = 377$ years [1]

A time longer than 300 years is required for the activity to drop to safe level, thus his claim is correct. [1]

Q4. (d) I support the development of nuclear power since

it is cheaper as the running cost is lower, and [2]

it is clean since it does not produce air pollution and acid rain. [2]

OR

I do not support the development of nuclear power since

it is dangerous as once accident occurs, it would be very serious, and [2]

it is expensive as the capital investment is very high. [2]

< accept other reasonable answers >

Q5. (a) (i) As 1 unit of nuclear power can only give 0.323 unit of electricity, the efficiency is 32.3%

Power generated by the reactor $= 1066 \div 32.3\% = 3300$ MW [1]

(ii) Power lost to the atmosphere $= 3300 \times (0.18 + 0.007) = 617$ MW [1]

(b) Power delivered to cooling water $= 3300 \times 0.49 = 1617$ MW [1]

In 1 s, volume of water circulating is 48 m^3

$\therefore$ mass $=$ volume $\times$ density $= 48 \times 10^3$ kg

By $E = m\,c\,\Delta T$ and consider the time of 1 s.

$\therefore\ (1617 \times 10^6) = (48 \times 1000) \times (4200) \times \Delta T$ [1]

$\therefore\ \Delta T = 8$ K [1]

(c) Mass defect :

$$\Delta m = (235.0409 + 1.0086) - (140.9141 + 91.9250 + 3 \times 1.0086)$$
$$= 0.1846 \text{ u}$$ [1]

Energy released in each fission :

$E = 0.1846 \times 931 \times 10^6 \times 1.6 \times 10^{-19} = 2.75 \times 10^{-11}$ J [1]

OR

$E = m\,c^2 = (0.1846 \times 1.661 \times 10^{-27}) \times (3 \times 10^8)^2 = 2.76 \times 10^{-11}$ J [1]

By $P = \dfrac{N}{t} E$

$\therefore\ (3300 \times 10^6) = \dfrac{N}{t} \times (2.75 \times 10^{-11})$

$\therefore\ \dfrac{N}{t} = 1.20 \times 10^{20}$ s^{-1} [1]

(d) Mass of U-235 needed in 1 s $= \dfrac{1.20 \times 10^{20}}{6.02 \times 10^{23}} \times 0.235 = 4.684 \times 10^{-5}$ kg [1]

Mass of U-235 needed in 10 years $= 4.684 \times 10^{-5} \times 10 \times 365 \times 24 \times 3600 = 1.48 \times 10^4$ kg [1]

Q6. (a) Mass defect $= (235.0439 \text{ u}) - (90.9234 \text{ u} + 141.9164 \text{ u} + 2 \times 1.0087 \text{ u})$ [1]

$= 0.1867 \text{ u}$ [1]

(b) Method ① :

$\dfrac{N}{t} = \dfrac{4.00\times10^{-5}}{0.235} \times 6.02 \times 10^{23} = 1.025 \times 10^{20} \text{ s}^{-1}$ [1]

$P = \dfrac{N}{t}E = (1.025 \times 10^{20}) \times [0.1867 \times 1.661 \times 10^{-27} \times (3 \times 10^{8})^{2}]$ [1]

$= 2.86 \times 10^{9} \text{ W}$ [1]

Method ② :

$\dfrac{N}{t} = \dfrac{4.00\times10^{-5}}{0.235} \times 6.02 \times 10^{23} = 1.025 \times 10^{20} \text{ s}^{-1}$ [1]

$P = \dfrac{N}{t}E = (1.025 \times 10^{20}) \times (0.1867 \times 931 \times 10^{6} \times 1.6 \times 10^{-19})$ [1]

$= 2.85 \times 10^{9} \text{ W}$ [1]

Method ③ :

$P = (4 \times 10^{-5}) \times \dfrac{0.1867}{235.0439} \times (3 \times 10^{8})^{2}$ [2]

$= 2.86 \times 10^{9} \text{ W}$ [1]

Q7. (a) mass defect : $\Delta m = \dfrac{173.8}{931} = 0.1867 \text{ u}$ [1]

$\therefore \quad 235.0439 = 141.9164 + 90.9234 + 2 \times m_n + 0.1867$ [1]

$\therefore \quad m_n = 1.0087 \text{ u}$ [1]

(b) Number of U-235 nuclei $= \dfrac{1.0\times10^{4}}{0.235} \times 6.02\times10^{23} = 2.56 \times 10^{28}$ [1]

Energy released $= 2.56 \times 10^{28} \times 173.8 \text{ MeV}$ [1]

$= 4.45 \times 10^{30} \text{ MeV}$ < **accept** 7.12×10^{17} J > [1]

(c) Total electrical energy released by the fuel rods $= 4.45 \times 10^{30} \times 10^{6} \times 1.6 \times 10^{-19} \times 40\%$

$= 2.848 \times 10^{17} \text{ J}$ [1]

By $E = P\,t$

$\therefore \quad (2.848 \times 10^{17}) = (500 \times 10^{6})\,t$

$\therefore \quad t = 5.70 \times 10^{8} \text{ s}$ < **accept** 1.58×10^{5} hours **or** 6590 days **or** 18.1 years > [1]

Q8. (a) The temperature in the Sun's core is so high that the hydrogen nuclei have sufficient large kinetic energy [1]

to overcome the strong electrostatic repulsion between them. [1]

Q8. (b) $\Delta m = (4)(1.00728) - 4.00150 = 0.02762\text{ u}$ [1]

$\Delta E = \Delta m\, c^2 = (0.02762)(1.661 \times 10^{-27})(3 \times 10^8)^2 = 4.13 \times 10^{-12}\text{ J}$ [1]

OR

$\Delta E = 0.02762 \times 931 \times 10^6 \times 1.6 \times 10^{-19} = 4.11 \times 10^{-12}\text{ J}$ [1]

(c) Number of hydrogen atoms in 1 kg of hydrogen $= \dfrac{(1)}{(1\times10^{-3})} \times (6.02 \times 10^{23})$

Number of fusion by 1 kg of hydrogen $= \dfrac{(1)}{(1\times10^{-3})} \times (6.02 \times 10^{23}) \times \dfrac{1}{4} = 1.505 \times 10^{26}$ [1]

Energy released by 1 kg of hydrogen $= 1.505 \times 10^{26} \times 4.13 \times 10^{-12}$

$= 6.22 \times 10^{14}\text{ J}$ < accept 6.14×10^{14} J to 6.28×10^{14} J > [1]

Q9. (a) $^{222}_{86}\text{Rn} \longrightarrow {}^{218}_{84}\text{Po} + {}^{4}_{2}\text{He}$ [1]

Mass defect $= 222.0176\text{ u} - (218.0090\text{ u} + 4.0026\text{ u}) = 0.006\text{ u}$ [1]

Energy released $= 0.006 \times 931 = 5.586\text{ MeV}$ < accept 5.59 MeV > [1]

(b) The mass ratio of the products is $m_{Po} : m_\alpha = 218 : 4$

By conservation of momentum, the speed ratio is $v_{Po} : v_\alpha = 4 : 218$ [1]

The kinetic energy of the products is $KE_{Po} : KE_\alpha = \frac{1}{2}(218)(4)^2 : \frac{1}{2}(4)(218)^2 = 4 : 218$ [1]

Thus, most of the energy released is given to the α.

(c) By $E = \dfrac{1}{2} m v^2$

$\therefore\ (5.586 \times 10^6 \times 1.6 \times 10^{-19}) = \dfrac{1}{2} \times (4.0026 \times 1.661 \times 10^{-27})\, v^2$ [1]

$\therefore\ v = 1.64 \times 10^7\text{ m s}^{-1}$ [1]

Q10. (a) $^{131}_{53}\text{I} \rightarrow {}^{131}_{54}\text{Xe} + {}^{0}_{-1}\text{e}$ < accept $^{0}_{-1}\beta$ > [1]

(b) (i) Number of atoms of I-131 in 1 kg $= \dfrac{1}{131\times10^{-3}} \times 6.02 \times 10^{23} = 4.60 \times 10^{24}$ [1]

Decay constant of I-131 : $k = \dfrac{\ln 2}{t_{1/2}} = \dfrac{\ln 2}{8.02\times24\times3600} = 1.00 \times 10^{-6}\text{ s}^{-1}$ [1]

Initial activity : $A_o = k N_o = (1.00 \times 10^{-6})(4.60 \times 10^{24}) = 4.60 \times 10^{18}\text{ Bq}$ [1]

Q10. (b) (ii) $\Delta m = 130.90612 - 130.90508 - 0.00054 = 5 \times 10^{-4}$ u [1]

$E = (5 \times 10^{-4}) \times (931 \times 10^{6} \times 1.6 \times 10^{-19})$ [1]

$= 7.45 \times 10^{-14}$ J [1]

OR

$E = \Delta m\, c^2 = (5 \times 10^{-4} \times 1.661 \times 10^{-27}) \times (3 \times 10^{8})^2$ [1]

$= 7.47 \times 10^{-14}$ J [1]

$P = (7.45 \times 10^{-14})(4.60 \times 10^{18}) = 3.43 \times 10^{5}$ W < accept 3.4×10^5 W to 3.5×10^5 W > [1]

(c) The decay of a radioisotope is determined by the half-life (**OR** decay constant). [1]

It cannot be changed by human factors or surrounding factors. [1]

(d) Any **ONE** of the following : [1]

* Iodine-123 emits γ rays that give less harmful effect to human body.
* The half-life of Iodine-123 is shorter, thus give less harmful effect to human body.
* Iodine-123 emits γ rays that have greater penetrating power to be detected outside the human body.

Q11. (a) ${}^{4}_{2}\text{He} + {}^{9}_{4}\text{Be} \longrightarrow {}^{12}_{6}\text{C} + {}^{A}_{Z}Q$ [1]

$A = 4 + 9 - 12 = 1$ and $Z = 2 + 4 - 6 = 0$ [1]

Q is a neutron [1]

(b) (i) $E = P\,t$

$= (500 \times 10^{6})(1 \times 24 \times 60 \times 60)$ [1]

$= 4.32 \times 10^{13}$ J [1]

(ii) Unit of electrical energy $= \dfrac{4.32 \times 10^{13}}{3600000}$ [1]

$= 1.2 \times 10^{7}$ kWh [1]

Cost $= 1.2 \times 10^{7} \times \$\,0.9$ [1]

$= \$\ 10\,800\,000$ [1]

(iii) Electrical energy produced by 1 kg of uranium $= 5.6 \times 10^{12} \times 30\%$ [1]

$= 1.68 \times 10^{12}$ J [1]

(iv) Mass of uranium fuel used in one day $= \dfrac{4.32 \times 10^{13}}{1.68 \times 10^{12}}$ [1]

$= 25.7$ kg [1]

Q11. (c) **Agree** [1]

<u>Reasons</u> : (any **THREE** of the following) < accept other reasonable answers > [3]

* Reserves of oil and coal are limited.
* Nuclear energy is cheaper.
* Nuclear energy causes less pollution.
* Nuclear energy does not produce greenhouse gases.

OR

Disagree [1]

<u>Reasons</u> : (any **THREE** of the following) < accept other reasonable answers > [3]

* The capital investment of a nuclear plant is high.
* The disposal of radioactive waste causes a serious problem.
* If there is accident, the damage to public is large.
* Some other resources of energy may be used, e.g. solar energy.

Q12. (a) When a neutron is captured by a Uranium-235 nucleus, the nucleus undergoes fission. [1]

It then splits into two smaller nuclei and together with some fission neutrons. [1]

During the fission, large amount of energy is released. [1]

(b) (i) These isotopes are produced as the **by-products** [1]

of the fission of the Uranium-235. [1]

(ii) Radioactive is used to describe an unstable nucleus [1]

that may emit α, β or γ radiation to form a more stable nucleus. [1]

(iii) Metal cans are used since β radiation cannot pass through the metal. [1]

(iv) Number of half-lives $= \dfrac{200}{25} = 8$ [1]

Initial activity $= 400 \times 2^8$ [1]

$= 102400$ Bq [1]

(v) Decay constant : $k = \dfrac{\ln 2}{t_{1/2}} = \dfrac{\ln 2}{25 \times 365 \times 24 \times 3600} = 8.79 \times 10^{-10}\ \text{s}^{-1}$ [1]

By $A_o = k N_o$ [1]

$\therefore\ (102400) = (8.79 \times 10^{-10})\, N_o$

$\therefore\ N_o = 1.16 \times 10^{14}$ [1]

(c) ① Nuclear fusion can only occur under very high temperature that is not easy to achieve. [1]

② No physical container can withstand the high temperature that fusion occurs. [1]

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- 所有筆記是由沈sir以三十四年教學及十多年考評機構的工作經驗而編寫，概括新高中課程的考試範圍
- 每課都附有過往三十四年的公開試相關題目作練習，並有詳細答案和解釋

物理知識融會貫通 · 考試上陣輕鬆

- 教學方式由淺入深，並附有很多生活化的例子，使同學能夠把物理學習和日常生活聯成一起，增加學習興趣
- 考試答題技巧，評分準則都會在課堂中詳細講解
- 沈Sir擅長以圖表、圖解深入淺出地闡釋艱深的物理概念，更設計了一套完整習作及詳解，涵蓋考試要點
- 堂上精闢的講解，令學生茅塞頓開，學習樂在其中，對考試充滿信心

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